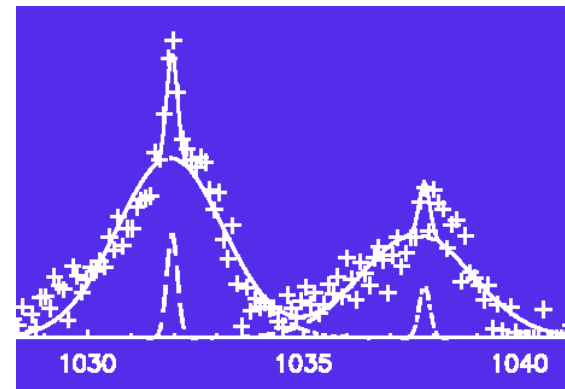
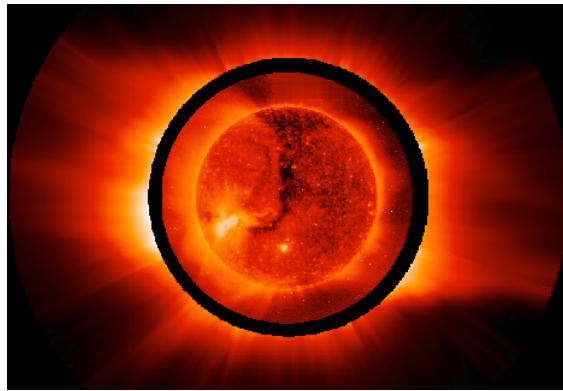


# Coronal Spectroscopy with LWS

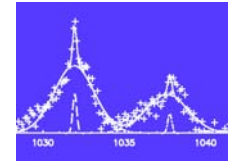


Steven R. Cranmer, Ruth Esser, John L. Kohl,  
John C. Raymond, Leonard Strachan, and Adriaan van Ballegooijen  
*Harvard-Smithsonian Center for Astrophysics*

This presentation describes how spectroscopy of the extended solar corona can meet scientific objectives of the Living with a Star (LWS) program, and provide useful real-time diagnostics of solar wind and CME conditions.

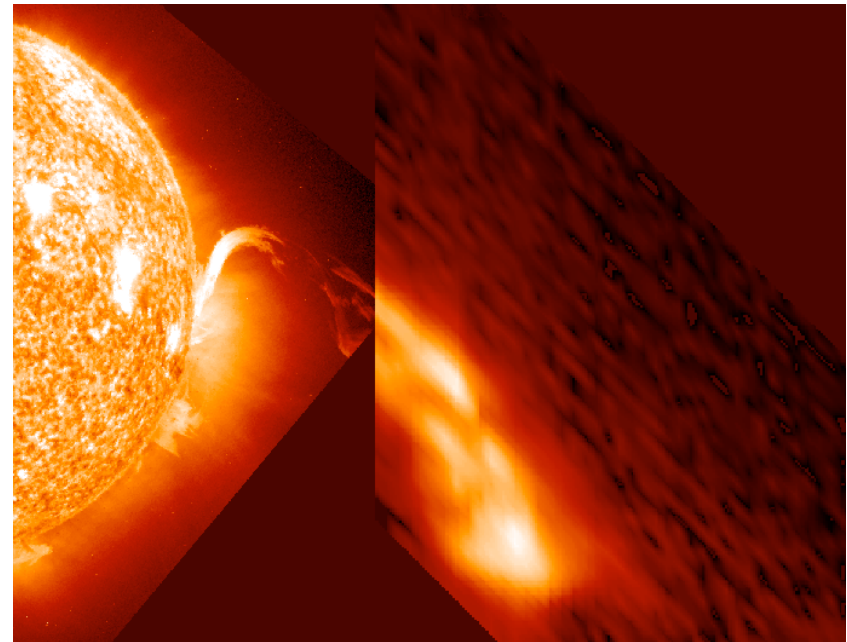


## Coronal Spectroscopy with LWS



### SCIENTIFIC GOAL

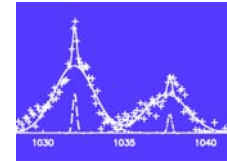
To achieve a fundamental understanding of the physical processes that heat the corona, accelerate the solar wind, and produce Coronal Mass Ejections (CMEs), and to predict the effects of these phenomena on the Earth's environment.



*Composite image of lower corona (from EIT/SOHO, on the left) and extended corona (from UVCS/SOHO, on the right) during a CME on 12 Dec. 1997*



## Coronal Spectroscopy with LWS

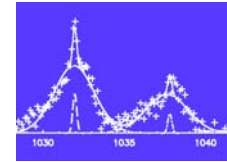


### THE ROLE OF CORONAL SPECTROSCOPY

- Spectroscopy uniquely provides the fundamental plasma parameters needed to identify the physical processes that create the heliosphere.
- Spectroscopy is essential in determining how coronal magnetic energy is transformed into kinetic and thermal energy in the solar wind and CMEs.
- Spectroscopy of the extended corona (1 to 10 solar radii) targets the plasma where a significant fraction of the heating and the majority of the acceleration occurs.
- Spectroscopy provides elemental abundances to trace solar plasma to the Earth, and provides CME magnetic helicities (the handedness and geometry of the twisted magnetic field) near the Sun.



# Coronal Spectroscopy with LWS



## MAJOR SCIENCE QUESTIONS TO BE ANSWERED BY SPECTROSCOPY

### Fast Solar Wind:

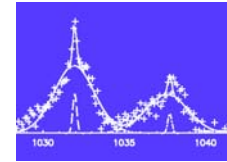
- Do the high-frequency ion-cyclotron waves that were determined by UVCS/SOHO to heat and accelerate minor ions also heat and accelerate protons and helium?
- How are high-frequency ion-cyclotron waves generated and damped in coronal holes?
- Do dense polar plumes mix with inter-plume plasma, or does only one component form the fast solar wind?

### Slow Solar Wind:

- What are the relative contributions to the slow wind from: (1) quasi-steady flow from edges of streamers (identified by UVCS/SOHO abundance measurements), and (2) transient openings of closed loops (identified by LASCO/SOHO kinematic measurements)?
- How do different types of streamers (quiescent equatorial vs. active mid-latitude) relate to the properties of the more distant solar wind?
- What are the roles of high and low frequency waves in accelerating and heating the slow wind?



## Coronal Spectroscopy with LWS



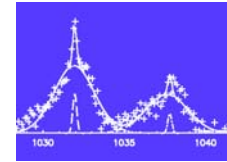
### MAJOR SCIENCE QUESTIONS TO BE ANSWERED BY SPECTROSCOPY (continued)

#### Coronal Mass Ejections:

- What are the physical processes that convert magnetic energy into the extended heating and acceleration of CMEs as observed by UVCS/SOHO and LASCO/SOHO? For example, what is the role of magnetic reconnection?
- How does the heating and acceleration of CMEs affect the evolution of their magnetic fields throughout the heliosphere (as determined by *in situ* measurements)?
- Does the magnetic helicity of CMEs that is measurable by coronal spectroscopy determine their helicity and geoeffectiveness near the Earth?
- Is the magnetic helicity removed from the Sun by CMEs consistent with the rate of helicity generation by the solar dynamo?



# Coronal Spectroscopy with LWS



## PHYSICAL PARAMETERS TO BE DETERMINED BY SPECTROSCOPY

To answer the major science questions, we need to determine the physical properties of the solar wind source regions and CMEs.

- Proton velocity distributions ← **from resonantly scattered H I Ly<sub>α</sub> spectral line profiles**
- Electron velocity distributions ← **from electron scattered H I Ly<sub>α</sub> spectral line profiles**

*(These particles contain the major source of pressure-gradient-acceleration of the solar wind, as well as the main energy difference between plume and inter-plume plasma)*

- Ion velocity distributions ← **from spectral line profiles**

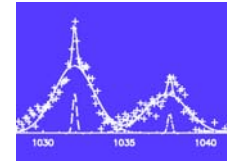
*(A large number of heavy ions, including helium, with a broad range of mass-to-charge ratios, is needed to determine the high-frequency wave power spectrum. This is necessary to understand wave generation and damping and the degree to which these waves accelerate the primary particles.)*

- Bulk 3D flow speeds ← **from Doppler shifts & Doppler dimming**
- Helicity of CME magnetic fields ← **from Doppler shifts & proper motions**

*(Measuring flow speeds is a direct probe of the changing kinetic energy content of the solar wind and CMEs, and provides a description of the evolution of CME magnetic helicity.)*



## Coronal Spectroscopy with LWS



### PHYSICAL PARAMETERS TO BE DETERMINED BY SPECTROSCOPY (continued)

- Local electron densities ← from ratios of EUV spectral line intensities
- Elemental abundances ← from EUV spectral line intensities
- Ionization state distributions ← from ratios of EUV spectral line intensities

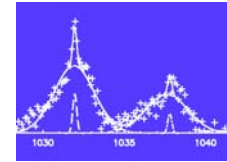
*(Combined with polarimetric and in situ observations, these spectroscopic measurements allow discrete parcels of plasma to be traced from the corona into interplanetary space.)*

- Coronal magnetic field strength ← from EUV spectropolarimetry

*(Measurement of the vector magnetic field using coronal spectroscopy is a new capability that still needs to be tested, but is expected to be extremely useful as a probe of geoeffectiveness.)*



## Coronal Spectroscopy with LWS



### COMBINED DATA SETS: More than the sum of their parts

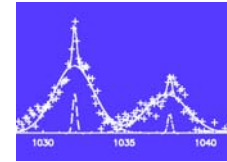
Spectroscopy, combined with imaging and polarimetry, is a powerful tool for answering fundamental questions about the properties of the solar corona & solar wind:

- **UV and visible spectroscopy of the solar disk and extended corona** provide physical parameters (temperatures, velocities, local densities, abundances, helicities) necessary to determine the basic physical processes.
- **EUV disk imaging** provides magnetic topology of loops and open-field regions, as well as global dynamics (proper motions) and evolution of structures over a wide range of temperatures, time scales, and sizes.
- **Visible coronagraphic imaging and polarimetry** provide the large-scale morphology of the corona, global dynamics (proper motions) of solar wind structures and CMEs, and electron column densities that are crucial for a quantitative understanding of the physics.





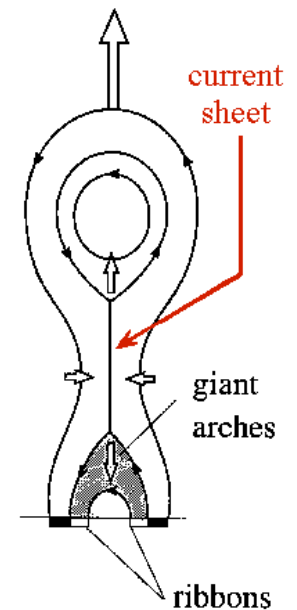
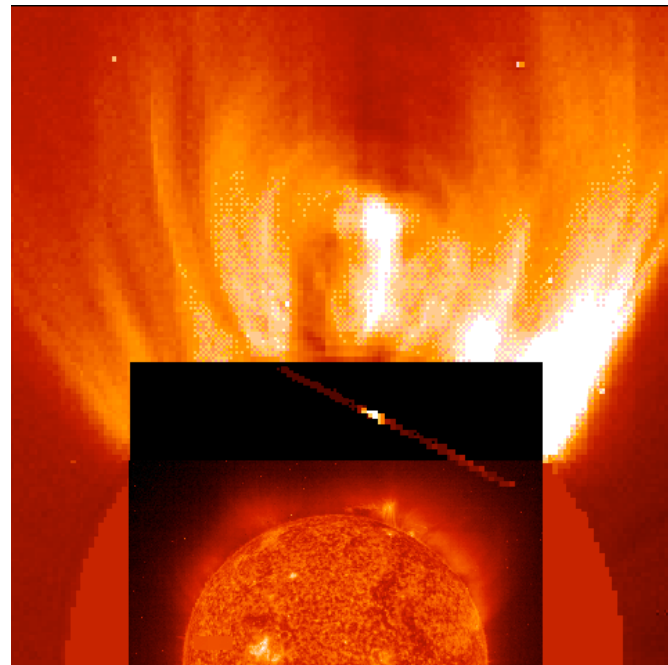
## Coronal Spectroscopy with LWS



### COMBINED DATA SETS: A proven record of synergy

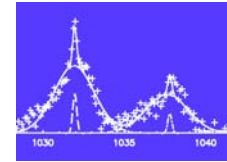
The UVCS, EIT, and LASCO instruments on SOHO have observed several CMEs and measured their plasma properties. On 23 March 1998, UVCS detected enhanced emission at the expected location of a **current sheet** located between magnetic arches (seen by EIT and *Yohkoh*) and the higher-altitude portion of the CME (seen by LASCO).

UVCS observed a narrow, extremely hot ( $T > 6$  million K) region emitting in [Fe XVIII] at  $2 R_{\odot}$  (*bright spot in black rectangle*). This coincided with the expected location of a current sheet, where magnetic reconnection and heating are predicted to occur. The lifetime and spatial extent of the emission agreed with the model of Forbes and Lin (2000).





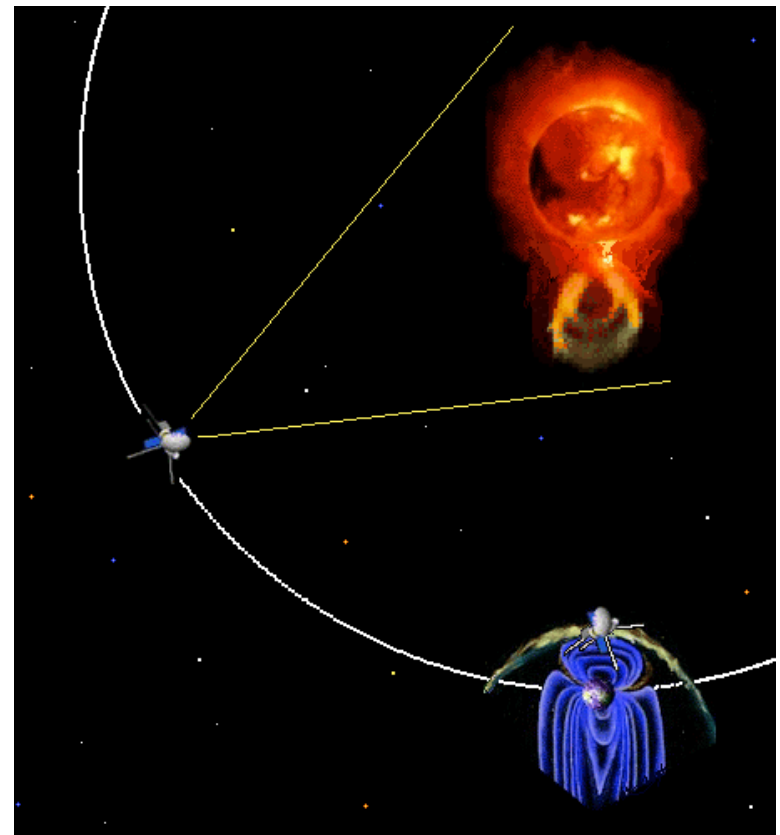
# Coronal Spectroscopy with LWS



## PROPOSED LWS SPECTROSCOPY MISSIONS

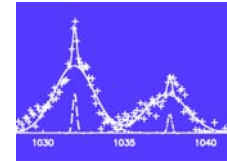
Two successive spectroscopy missions will best bridge the gap between **research** and **operations**:

- An Earth-orbiting spacecraft designed to answer basic science questions and optimize diagnostics for characterization of CMEs and solar wind streams. Contains:
  - Next-generation UVCS
  - Next-generation LASCO
  - Next-generation EUV disk spectrograph
- A Sentinel spacecraft optimized to detect and characterize CMEs and solar wind streams that are **directed toward the Earth**, in order to develop specific operational data products and strategies.
  - Positioned near L4 or L5
  - Instrument definition to be based on proven diagnostics from Earth-orbiting spacecraft.





# Coronal Spectroscopy with LWS



## DATA PRODUCTS

All data will be available immediately to the scientific and operational user communities, independently of the PI and instrument team. Automated software will produce the following data products:

### Earth-orbiting spacecraft:

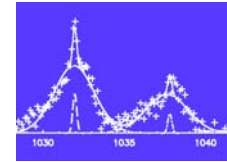
- Maps of the physical properties (*temperature, velocity, density, abundance, helicity*) of coronal holes, streamers, and CMEs.
- Images and movies that correlate solar disk activity to properties of off-limb and halo CMEs.

### L4/L5 Sentinel spacecraft:

- Real-time visualizations of the physical properties (*e.g., temperature & helicity*) of Earth-directed CMEs that determine their severity.
- Real-time visualizations of the physical properties of Earth-directed solar wind streams.



# Coronal Spectroscopy with LWS



## SUMMARY

- Coronal spectroscopy is needed to understand how the solar wind and CMEs are produced.
- An Earth-orbiting spacecraft can develop the off-limb diagnostic techniques necessary for an L4/L5 Sentinel. This mission can characterize the coronal plasma (both on the disk and in the extended corona), which is essential to the development of the capability to **predict** CMEs and other transient phenomena.
- An L4/L5-orbiting Sentinel spacecraft can **detect** Earth-directed CMEs and evaluate their geoeffectiveness based on their coronal properties.

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**<http://cfa-www.harvard.edu/uvcs/>**